

Claims

1. An optical waveguide for outputting light of a substantially single predetermined wavelength, the optical waveguide comprising a light conducting medium (2) defining a longitudinally extending optical path (15) for guiding the light, the optical path (15) extending longitudinally between respective spaced apart first and second ends (8,9), and a means (20,21) for causing partial longitudinal reflections of the light along the optical path (15) at at least two spaced apart partial reflecting locations (20) along the optical path (15) for deriving light of the predetermined wavelength, characterised in that the means (20,21) for causing the partial reflections locates the reflecting locations (20) along the optical path (15) at distances from the first end (8) along the optical path (15) which are functions of the effective optical length of the optical path (15) taking account of alteration to the actual length of the optical path (15) resulting from the affect of the means (20,21) for causing the partial reflections on the actual length of the optical path (15).
2. An optical waveguide as claimed in Claim 1 or 2 characterised in that the means (20,21) for causing the partial reflections of the light at the at least two reflecting locations (20) comprises a refractive index altering means (21) for altering the effective refractive index of the light conducting medium (2) presented to light passing along the optical path (15) at each of the at least two reflecting locations (20) for causing the partial reflections.
3. An optical waveguide as claimed in Claim 2 characterised in that the length of each reflecting location (20) in the longitudinal direction of the optical path (15) is relatively short.
4. An optical waveguide as claimed in Claim 2 or 3 characterised in that the length of each reflecting location (20) in the longitudinal direction of the optical path is in the range of 0.3 microns to 200 microns.
5. An optical waveguide as claimed in Claim 4 characterised in that the length of each reflecting location (20) in the longitudinal direction of the optical path is in the range of 1 micron to 4 microns.

6. An optical waveguide as claimed in any of Claims 3 to 5 characterised in that the respective lengths of the reflecting locations (20) along the optical path may be the same or different.
- 5 7. An optical waveguide as claimed in any of Claims 3 to 6 characterised in that the effective refractive indices of the respective reflecting locations (20) may be the same or different.
- 10 8. An optical waveguide as claimed in any of Claims 2 to 7 characterised in that the distance of each reflecting location (20) from the first end (8) along the optical path is a function of the product of the actual length of the optical path (15) and the actual refractive index of the light conducting medium (2) defining the optical path, less the sum of the products of the lengths of the reflecting locations (20) and the
- 15 differences between respective effective refractive indices of the reflecting locations (20) and the actual refractive index of the light conducting medium defining the optical path (15).
9. An optical waveguide as claimed in any of Claims 2 to 8 characterised in that
- 20 the distance of each reflecting location (20) from the first end along the optical path is a function of the sum of the products of the lengths of the reflecting locations (20) intervening between the first end (8) and that reflecting location (20) and the differences between respective effective refractive indices of the reflecting locations and the actual refractive index of the light conducting medium defining the optical
- 25 path.
10. An optical waveguide as claimed in any of Claims 2 to 9 characterised in that the distance of each reflecting location (20) from the first end (8) along the optical path (15) is a function of the product of half the length of that reflecting location and
- 30 the difference between its effective refractive index and the actual refractive index of the light conducting medium defining the optical path.
11. An optical waveguide as claimed in any of Claims 2 to 10 characterised in

that the distance of each reflecting location from the first end (8) along the optical path (15) is a function of the actual refractive index of the light conducting medium (2) defining the light path (15).

- 5 12. An optical waveguide as claimed in any of Claims 2 to 11 characterised in that the distance of the  $p^{\text{th}}$  reflecting location (20) from the first end (8) along the optical path (15) is provided by the formula:

$$10 \quad L = \frac{X \{ L_{\text{device}} n_{\text{device}} - \sum_i l_i \Delta n_i \} + \sum_{i=1}^{p-1} l_i \Delta n_i + \frac{1}{2} l_p \Delta n_p}{n_{\text{device}}}$$

- where: L is the distance of the  $p^{\text{th}}$  reflecting location from the first end along the optical path,
- 15 X is the fraction of the actual optical length at which the element is to be placed,
- $L_{\text{device}}$  is the actual length of the optical path,
- $n_{\text{device}}$  is the average refractive index of the light conducting layers of the unperturbed light conducting medium of the optical path presented to the light,
- 20  $l_i$  is the length of the  $i^{\text{th}}$  reflecting location in the direction of the optical path,
- $\Delta n_i$  is the difference between the effective refractive index of the  $i^{\text{th}}$  partial reflecting location and the average refractive index of the unperturbed optical path,
- $l_p$  is the length of the  $p^{\text{th}}$  reflecting location in the direction of the optical path, and
- $\Delta n_p$  is the difference between the effective refractive index of the  $p^{\text{th}}$  partial reflecting location and the average refractive index of the optical path.
- 25

13. An optical waveguide as claimed in any of Claims 2 to 12 characterised in that the refractive index altering means (21) comprises a plurality of refractive index altering elements (20) one refractive index altering element being provided for each reflecting location, the respective refractive index altering elements being located distances from the first end along the optical path similar to the distances from the first end of the corresponding reflecting location.
- 30

14. An optical waveguide as claimed in Claim 13 characterised in that each

refractive index altering element (21) is located spaced apart from an active region within which the optical path is defined.

15. An optical waveguide as claimed in Claim 13 or 14 characterised in that each  
5 refractive index altering element (21) is provided by a refractive index altering groove (21) formed in a medium adjacent the light conducting medium but spaced apart therefrom.

16. An optical waveguide as claimed in Claim 15 characterised in that the depth  
10 of the refractive index altering grooves (21) may be the same or different.

17. An optical waveguide as claimed in any of Claims 14 to 16 characterised in that each refractive index altering element (20) extends substantially transversely relative to the optical path (15).  
15

18. An optical waveguide as claimed in any of Claims 2 to 12 characterised in that the respective reflecting locations (20) are formed by a dopant.

19. An optical waveguide as claimed in any of Claims 2 to 18 characterised in  
20 that the distance from the first end along the optical path to each reflecting location is measured to the centre of the reflecting location.

20. An optical waveguide as claimed in any preceding claim characterised in that the optical waveguide is a waveguide for laser light.  
25

21. An optical waveguide as claimed in any preceding claim characterised in that the waveguide is a semiconductor laser light generating device.

22. An optical waveguide as claimed in any preceding claim characterised in that  
30 the optical waveguide is a passive semiconductor waveguide.

23. An optical waveguide as claimed in Claim 21 or 22 characterised in that a ridge (14) is formed on a surface of the semiconductor laser waveguide for defining

the optical path through the light conducting medium.

24. An optical waveguide as claimed in Claim 23 characterised in that the refractive index altering elements (21) are located in the ridge (14) at locations  
5 corresponding to the reflecting location.

25. An optical waveguide as claimed in Claim 23 or 24 characterised in that the refractive index altering elements (21) are located in the ridge (14) at locations  
10 directly corresponding to the partial reflecting location (20).

26. An optical waveguide as claimed in any of Claims 20 to 22 characterised in that the optical waveguide is a buried heterostructure laser.

27. An optical waveguide as claimed in any of Claims 2 to 19 characterised in  
15 that the optical waveguide comprises a fibre optic waveguide.

28. An optical waveguide as claimed in any of Claims 2 to 19 characterised in that the waveguide is a filter comprising an optical fibre core which forms the light conducting medium for defining the optical path, the optical fibre core being  
20 surrounded by cladding medium of refractive index different to that of the optical fibre core.

29. An optical waveguide as claimed in Claim 28 characterised in that each refractive index altering element (20) is located in and extends around the cladding  
25 medium.

30. An optical waveguide as claimed in any preceding claim characterised in that the means (20,21) for causing the partial reflections causes the partial reflections at at least three reflecting locations (20) along the optical path (15).  
30

31. An optical waveguide as claimed in any preceding claim characterised in that the reflecting locations (20) are provided at respective distances from the first end which correspond to the following fractions of the actual length of the optical path,

namely,  $1/14$ ,  $1/7$ ,  $3/14$ ,  $2/7$ ,  $3/7$ ,  $4/7$  and  $5/7$  along the optical path.

32. An optical waveguide as claimed in Claim 31 characterised in that the respective distances along the optical path from the first end at which the reflecting  
5 locations are located which correspond to the fractions of the actual length of the optical path of  $1/14$ ,  $1/7$ ,  $3/14$ ,  $2/7$ ,  $3/7$ ,  $4/7$  and  $5/7$  are 39.3, 78.6, 118.0, 157.3, 235.9, 314.5 and 393.1 microns for a waveguide of actual length of 550 microns.

33. An optical waveguide as claimed in any of Claims 1 to 30 characterised in  
10 that reflecting locations (20) are provided at respective distances from the first end which correspond to the following fractions of the actual length of the optical path, namely,  $1/16$ ,  $1/8$ ,  $3/16$ ,  $1/4$ ,  $5/16$ ,  $3/8$ ,  $1/2$ ,  $5/8$  and  $3/4$  along the optical path.

34. An optical waveguide as claimed in Claim 33 characterised in that the  
15 respective distances along the optical path from the first end at which the reflecting locations are located which correspond to the fractions of the actual length of the optical path of  $1/16$ ,  $1/8$ ,  $3/16$ ,  $1/4$ ,  $5/16$ ,  $3/8$ ,  $1/2$ ,  $5/8$  and  $3/4$  are 18.74, 37.55, 56.36, 75.16, 93.97, 112.78, 150.26, 187.74 and 225.23 microns for a waveguide of actual length of 300 microns.

35. An optical waveguide as claimed in any preceding claim comprising a  
20 plurality of optical waveguides provided in the form of an array (50).

36. An optical waveguide as claimed in Claim 35 characterised in that the  
25 wavelength of the light outputted from the respective waveguides of the array may be the same or different.

37. An array of optical waveguides characterised in that the respective optical  
30 waveguides of the array are optical waveguides as claimed in any preceding claim.

38. A method for providing an optical waveguide for outputting light of a substantially single predetermined wavelength, the method comprising providing a light conducting medium (2) defining a longitudinally extending optical path (15) for

guiding the light, the optical path (15) extending longitudinally between respective spaced apart first and second ends (8,9), and providing a means (20,21) for causing partial longitudinal reflections of the light along the optical path (15) at at least two spaced apart partial reflecting locations (20) along the optical path for deriving the  
5 light of the predetermined wavelength, characterised in that the means (20,21) for causing the partial reflections are provided such that the reflecting locations (20) are at distances from the first end (8) along the optical path (15) which are functions of the effective optical length of the optical path (15) taking account of alteration to the actual length of the optical path (15) resulting from the affect of the means (20,21)  
10 for causing the partial reflections on the actual length of the optical path (15).

39. A method as claimed in Claim 38 characterised in that the means (20,21) for causing the partial reflections of the light at the at least two reflecting locations (20) is provided by a refractive index altering means (21) for altering the refractive index  
15 of the light conducting medium (2) presented to light passing along the optical path (15) at each of the at least two reflecting locations (20) for causing the partial reflections.

40. A method as claimed in Claim 39 characterised in that the length of each  
20 reflecting location (20) in the longitudinal direction of the optical path (15) is relatively short.

41. A method as claimed in Claim 39 or 40 characterised in that the length of each reflecting location (20) in the longitudinal direction of the optical path is in the  
25 range of 0.3 microns to 200 microns.

42. A method as claimed in any of Claims 39 to 41 characterised in that the respective lengths of the partial reflecting locations along the optical path may be the same or different.

30 43. A method as claimed in any of Claims 39 to 42 characterised in that the effective refractive index of the respective reflecting locations may be the same or different.

44. A method as claimed in any of Claims 33 to 43 characterised in that the distance of each reflecting location (20) from the first end (8) along the optical path is a function of the product of the actual length of the optical path (15) and the actual refractive index of the light conducting medium (2) defining the optical path, less the sum of the products of the lengths of the reflecting locations (20) and the differences between respective effective refractive indices of the reflecting locations (20) and the actual refractive index of the light conducting medium defining the optical path (15).

45. A method as claimed in any of Claims 40 to 44 characterised in that the distance of each reflecting location (20) from the first end along the optical path is a function of the sum of the products of the lengths of the reflecting locations (20) intervening between the first end (8) and that reflecting location (20) and the differences between respective effective refractive indices of the reflecting locations and the actual refractive index of the light conducting medium defining the optical path.

46. A method as claimed in any of Claims 40 to 45 characterised in that the distance of each reflecting location (20) from the first end (8) along the optical path (15) is a function of the product of half the length of that reflecting location and the difference between its effective refractive index and the actual refractive index of the light conducting medium defining the optical path.

47. A method as claimed in any of Claims 40 to 46 characterised in that the distance of each reflecting location from the first end (8) along the optical path (15) is a function of the actual refractive index of the light conducting medium (2) defining the light path (15).

48. A method as claimed in any of Claims 40 to 47 characterised in that the distance of the  $p^{\text{th}}$  reflecting location (20) from the first end (8) along the optical path (15) is provided by the formula:



$$L = \frac{X \{ L_{\text{device}} n_{\text{device}} - \sum_i l_i \Delta n_i \} + \sum_{i=1}^{p-1} l_i \Delta n_i + \frac{1}{2} l_p \Delta n_p}{n_{\text{device}}}$$

where: L is the distance of the  $p^{\text{th}}$  reflecting location from the first end along the optical path,

X is the fraction of the actual optical length at which the element is to be placed,

10  $L_{\text{device}}$  is the actual length of the optical path,

$n_{\text{device}}$  is the average refractive index of the light conducting layers of the unperturbed light conducting medium of the optical path presented to the light,

$l_i$  is the length of the  $i^{\text{th}}$  reflecting location in the direction of the optical path,

15  $\Delta n_i$  is the difference between the effective refractive index of the  $i^{\text{th}}$  partial reflecting location and the average refractive index of the optical path,

$l_p$  is the length of the  $p^{\text{th}}$  reflecting location in the direction of the optical path, and

$\Delta n_p$  is the difference between the effective refractive index of the  $p^{\text{th}}$  partial reflecting location and the average refractive index of the unperturbed optical path.

20 49. A method as claimed in any of Claims 40 to 48 characterised in that the refractive index altering means (21) comprises a plurality of refractive index altering elements (20) one refractive index altering element being provided for each reflecting location, the respective refractive index altering elements being located distances from the first end along the optical path similar to the distances from the  
25 first end of the corresponding reflecting location.

50. A method as claimed in Claim 49 characterised in that each refractive index altering element (21) is located spaced apart from an active region within which the optical path is defined.

30

51. A method as claimed in Claim 49 or 50 characterised in that each refractive index altering element (21) is provided by a refractive index altering groove (21) formed in a medium adjacent the light conducting medium but spaced apart therefrom.

52. A method as claimed in Claim 51 characterised in that the depth of the refractive index altering grooves (21) may be the same or different.
- 5 53. A method as claimed in any of Claims 49 to 52 characterised in that each refractive index altering element (20) extending substantially transversely relative to the optical path (15).
54. A method as claimed in any of Claims 40 to 48 characterised in that the  
10 respective reflecting locations (20) are formed by a dopant.
55. A method as claimed in any of Claims 39 to 53 characterised in that the distance from the first end along the optical path to each reflecting location is measured to the centre of the reflecting location.
- 15 56. A method as claimed in any of Claims 38 to 55 characterised in that the optical waveguide is a waveguide for laser light.
57. A method as claimed in any of Claims 38 to 56 characterised in that the  
20 waveguide is a semiconductor laser light generating device.
58. A method as claimed in any of Claims 38 to 57 characterised in that that the optical waveguide is a passive semiconductor waveguide.
- 25 59. A method as claimed in Claim 57 or 58 characterised in that a ridge (14) is formed on a surface of the semiconductor laser waveguide for defining the optical path through the light conducting medium.
60. A method as claimed in Claim 59 characterised in that the refractive index  
30 altering elements (21) are located in the ridge (14) at locations corresponding to the reflecting location.
61. A method as claimed in Claim 59 or 60 characterised in that the refractive

index altering elements (21) are located in the ridge (14) at locations directly corresponding to the partial reflecting location (20).

62. A method as claimed in any of Claims 56 to 58 characterised in that the optical waveguide is a buried heterostructure laser.

63. A method as claimed in any of Claims 39 to 55 characterised in that the optical waveguide comprises a fibre optic waveguide.

64. A method as claimed in any of Claims 39 to 55 characterised in that the waveguide is a filter comprising an optical fibre core which forms the light conducting medium for defining the optical path, the optical fibre core being surrounded by cladding medium of refractive index different to that of the optical fibre core.

65. A method as claimed in Claim 64 characterised in that each refractive index altering element (20) is located in and extends around the cladding medium.

66. A method as claimed in any of Claims 38 to 65 characterised in that the means (20,21) for causing the partial reflections causes the partial reflections at at least three reflecting locations (20) along the optical path (15).

67. An optical waveguide as claimed in any of Claims 38 to 66 characterised in that the reflecting locations (20) are provided at respective distances from the first end which correspond to the following fractions of the actual length of the optical path, namely,  $1/14$ ,  $1/7$ ,  $3/14$ ,  $2/7$ ,  $3/7$ ,  $4/7$  and  $5/7$  along the optical path.

68. A method as claimed in Claim 67 characterised in that the respective distances along the optical path from the first end at which the reflecting locations are located which correspond to the fractions of the actual length of the optical path of  $1/14$ ,  $1/7$ ,  $3/14$ ,  $2/7$ ,  $3/7$ ,  $4/7$  and  $5/7$  are 39.3, 78.6, 118.0, 157.3, 235.9, 314.5 and 393.1 microns for a waveguide of actual length of 550 microns.

69. A method as claimed in any of Claims 38 to 66 characterised in that reflecting

locations (20) are provided at respective distances from the first end which correspond to the following fractions of the actual length of the optical path, namely,  $1/16$ ,  $1/8$ ,  $3/16$ ,  $1/4$ ,  $5/16$ ,  $3/8$ ,  $1/2$ ,  $5/8$  and  $3/4$  along the optical path.

5 70. A method as claimed in Claim 69 characterised in that the respective distances along the optical path from the first end at which the reflecting locations are located which correspond to the fractions of the actual length of the optical path of  $1/16$ ,  $1/8$ ,  $3/16$ ,  $1/4$ ,  $5/16$ ,  $3/8$ ,  $1/2$ ,  $5/8$  and  $3/4$  are 18.74, 37.55, 56.36, 75.16, 93.97, 112.78, 150.26, 187.74 and 225.23 microns for a waveguide of actual length  
10 of 300 microns.

71. A method as claimed in any of Claims 38 to 65 comprising a plurality of optical waveguides provided in the form of an array (50).

15 72. A method as claimed in Claim 71 characterised in that the wavelength of the light outputted from the respective waveguides of the array may be the same or different.

*add all*